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THE PRE-CAMBRIAN SEDIMENTARY ROCKS IN THE HIGHLANDS OF NEW JERSEY.¹

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The following paper is presented to the Congress (1), to furnish a sample of much of the Pre-Cambrian geology of the eastern United States; (2), to suggest in part the difficulty felt by the students of the eastern Pre-Cambrian in accepting the apparently complicated classifications based upon the phenomena observed in the Lake Superior region and the adjacent portions of Canada; and (3), to emphasize the fact that even in the greatly metamorphosed Pre-Cambrian areas in the central-eastern United States, distinctly characterized sediments may sometimes be found, and to intimate that their absence from other similar areas does not necessarily imply that they were never present in them.

In nearly all areas that contain Pre-Cambrian rocks close investigation has revealed the presence of sedimentaries well enough preserved to leave no doubt in the mind of the investigator as to their sedimentary character. The Highlands of New Jersey furnish no exception to the rule. The well-known white limestone, which contains the deposits of franklinite and zincite at Franklin Furnace, has been recognized as Pre-Cambrian by all geologists since the work of WESTGATE,² on Jenny Jump mountain, in 1894, and the work of WOLFF and BROOKS,³ at Franklin Furnace in 1898. WOLFF and BROOKS named it the Franklin limestone.

It was not known until somewhat later, however, that fragmental rocks similar to some of those in the Pre-Cambrian series of the Adirondacks in New York, and of the Reading hills in Pennsylvania are associated with the Franklin limestone. SPENCER,⁴ in 1908, mentioned thin layers of sandstone. In his description of the Andover mine⁵ he declares that layers of siliceous breccia and indurated carbonaceous shales, aggregating 100 feet in thickness and outcropping for 1,300 feet, are associated with the ores. These dip

¹ Published with the permission of the Director of the U. S. Geological Survey.

² WESTGATE, L. C., Amer. Geologist, Vol. XIV, 1894, pp. 369-379, and Ann. Rep. State Geol. (N. J.) for 1895, pp. 21-26.

³ WOLFF, J. E., and BROOKS, A. H., Eighteenth Annual Report, U. S. Geol. Survey, Pt. 2, 1898, pp. 431-457.

⁴ SPENCER, A. C., Franklin Furnace folio (No. 161), Geol. Atlas U. S., U. S. Geol. Survey, 1908, p. 3.

⁵ Ibid.

from 25° S. E. to nearly vertical. "The presence of coarsely crystalline white limestone in the vicinity suggests that the siliceous beds found at the mine are part of a series of sedimentary beds belonging with the white limestone of the Franklin region." Again, at the Simpson and the Cedar Hill mines, near McAfee, he describes the hematite as occurring in layers or irregular deposits interbedded with layers of sandstone and shaly material that dip S. E. and are overlain by white limestone (p. 23). At the Cedar Hill mine "a stratum of hard green rock about 50 feet thick stands in a nearly vertical position between walls of white limestone. It contains abundant pebble-like, but more or less angular, fragments of quartz up to about one-fourth of an inch in diameter set in a matrix of chlorite, and throughout the mass, as seen near the surface, there is considerable red hematite in an amorphous or non-crystalline condition." This occurs in the interstices between the chlorite particles. BAYLEY¹ corroborates SPENCER's observations in the Franklin Furnace quadrangle and adds that the ore pits of the Fulmer mine, near Phillipsburg, are in a great mass of quartzite, south of which are yellow and light purple slaty or schistose rocks that resemble in many respects the sheared volcanics of South mountain in Pennsylvania. Some of the slates are very quartzose, and others are steatitic. Some are fine grained and dense, like rhyolites. Conglomeratic quartzite layers are interbedded with the slates, but they are not common. Farther northwest the slates are replaced by quartzitic conglomerates similar to those at the Andover, Simpson and Cedar Hill mines. The ore is merely a portion of the conglomerate more ferruginous than elsewhere in consequence of the presence of hematite in the interstices between the quartz grains. The white limestone occurs both north and south of the quartzites but the contacts are covered.

In addition to quartzites and slates there are also associated with the Franklin limestone in many places a fine grained, very quartzose mica-schist, which in some places contains a considerable content of graphite. In Tuxedo Park, N.Y., which is just north of New Jersey, STEWART² describes the limestone as occurring in a lens 250 feet thick and 3,000 feet long, surrounded by coarse-grained gneiss. With the limestone are associated pegmatite and a graphite-quartz-schist which consists of quartz, feldspar, biotite and graphite. The last two minerals are frequently intergrown with one another in alternate plates. Although its constituents are intercrystallized, nevertheless the rock is regarded as a sediment.

The limestone and associated schists at this place occupy an area a mile long and 20—300 feet wide, and are surrounded by gneisses. The beds strike N.E. and dip at a moderately high angle (30°—40°) S.E. Toward the northern end of the area the principal rock exposed is a coarse grained, gray marble composed of white calcite, large flakes of brown mica and irregular masses of brown chondrodite. Locally, it also contains considerable graphite.

¹ BAYLEY, W. S., *Iron mines and mining in New Jersey*; Final Report Series, Vol. VII, Geol. Survey of New Jersey, 1910, pp. 77 and 84.

² BAYLEY, W. S., and STEWART, A. C., *Note on the occurrence of graphite schist in Tuxedo Park, N.Y.*; Econ. Geol., Vol. III, 1908, p. 535.

This limestone is cut by belts of pegmatite which run the length of the area, and by several small masses with oval sections. On the other hand, several small areas of the limestone are entirely enclosed in pegmatite and a small area of the same rock occurs off to one side of the main mass, at the contact of a pegmatite band with the country gneiss. At the extreme northeast end of the belt is a layer of graphite-quartz-schist which extends through the centre of the limestone. Its exposed length is 900 feet and its width is from 20 feet to 60 feet.

No limestone has been observed in the southwest portion of the area, where the series is represented by the graphitic schist alone. This rock occupies several long, narrow belts from several feet to 100 feet wide and entirely surrounded by pegmatite. It is so rich in graphite that it has been proposed to mine it.

The association of micaceous schist with the Franklin limestone is not by any means limited to the Highlands in New Jersey. MILLER,¹ in his discussion of the graphite of Pennsylvania, mentions that the mineral occurs in sedimentary deposits and igneous rocks that intrude them. Among the former he mentions a white crystalline limestone, correlated with the Franklin limestone, which, he states, is associated with graphitic gneiss of which it is apparently merely a phase. He states that these acid gneisses were mapped with the Baltimore gneiss (Pre-Cambrian) by Miss BASCOM² on her map of the Trenton quadrangle, but on the forthcoming map of the Phoenixville quadrangle they will be designated by the distinctive name, Pickering gneiss. The gneiss is described by MILLER as being composed primarily of feldspar, quartz, biotite, hornblende, calcite and graphite, with pyrite pyrrhotite, magnetite, epidote, sillimanite, garnet and other alteration products of the primary minerals as accessories. It is, however, extremely variable in composition. Some layers are practically quartz-schists; others contain biotite but no graphite; others contain both biotite and graphite, while others contain so much calcite that they might fairly be called calcareous gneisses. In many places it is impossible to draw a sharp line between the Franklin limestone and the calcareous graphitic gneisses. "The two formations were formed originally as contemporaneous sediments that varied in different places. In some localities fairly pure limestone was being deposited while in adjacent regions were accumulating calcareous muds or siliceous muds in which there was little or no calcareous material. When these sediments were later metamorphosed, the beds composed mainly of calcareous matter formed the rocks called the Franklin limestone; the calcareous muds gave rise to the calcareous graphitic gneisses; the muds with little calcareous matter formed the bulk of the Pickering gneiss; and the more siliceous sediments formed the quartz-schists. If the limestone and the gneiss are conformable, as believed, with the limestone intercalated within the gneiss, the logical conclusion follows: that the two are of contempor-

¹ MILLER, B. J., *The geology of the graphite deposits of Pennsylvania*; Econ. Geol., Vol. VII, 1912, p. 762.

² Trenton folio (No. 167), Geol. Atlas U. S., U. S. G. S., 1908.

aneous origin and represent merely different lithologic phases of the same series of sediments."

In New Jersey, as has been stated, the Franklin limestone in many places is associated with slates, quartzites, conglomerates and micaceous

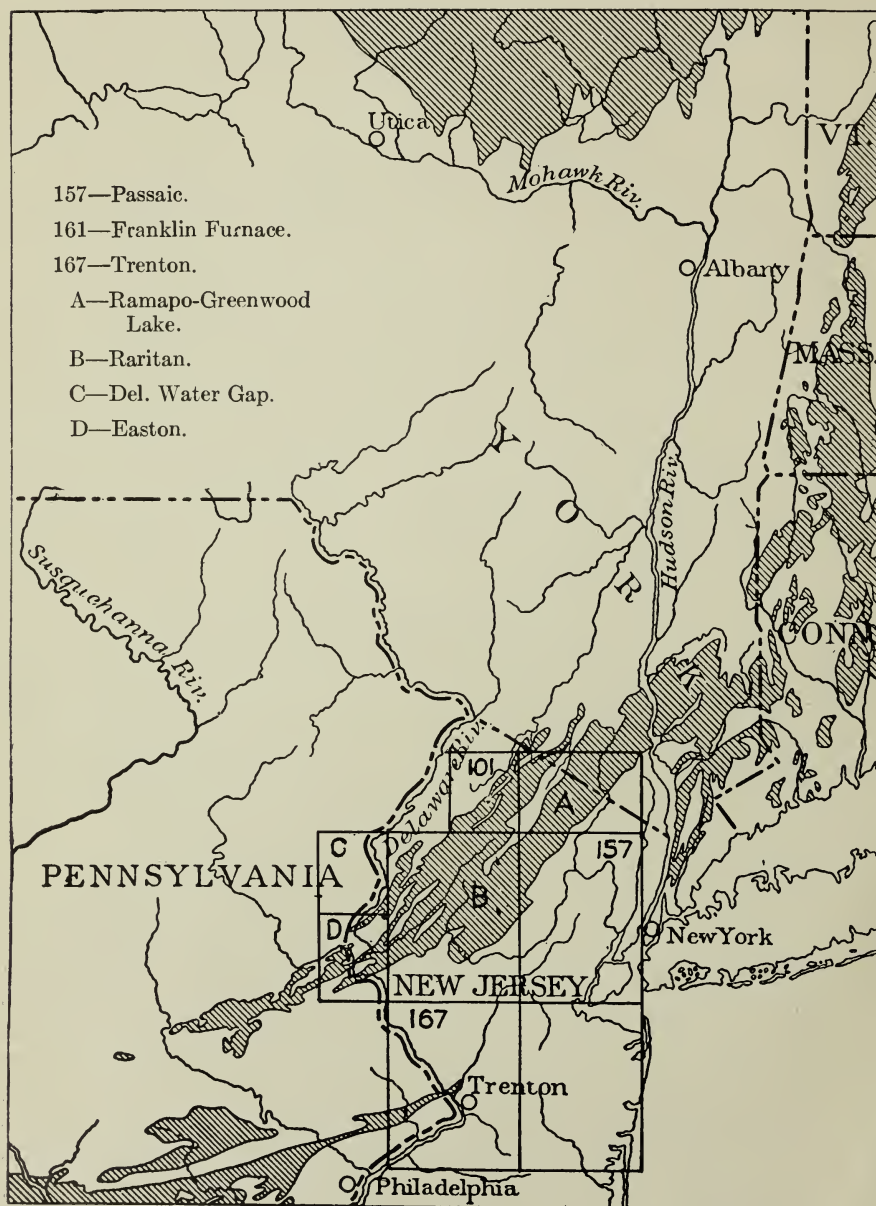


FIG. 1.—Sketch map showing areas of Pre-Cambrian crystalline rocks (shaded) in New Jersey and adjacent states, with the names of the quadrangles in New Jersey upon which folios have been published, or are in course of publication, by the U. S. Geological Survey. The names preceded by figures are of folios that have been published.

schists. It contains also, in some places, layers of calcareous gneisses that are not very unlike those described by MILLER as being present in the Pickering gneiss. While limestone is the most prominent member of the series, and in some localities the only member observable, in other localities the clastic rocks are also prominent.

The most important exposures of the series are in the Delaware Water-gap, and the Easton and Franklin Furnace quadrangles.

A belt of limestone extends from the Pequest Furnace westward to Hazen, a distance of about two and a half miles, with an average width of about three-fourths of a mile. Here the predominant rock is limestone, which at one place is so richly impregnated with sphalerite that attempts have been made to mine it as a zinc ore. It varies from a fine grained white, gray, or bluish marble, containing a few quartz grains, pyrite crystals, graphite flakes and crystals of white pyroxene, to a mottled opheicalcite, containing abundant chondrodite, pyroxene, garnet, phlogopite, tremolite, magnetite, and an occasional crystal of tourmaline and sphene. In some places serpentine and talc are common. These components are especially abundant where the marble is cut by pegmatite or by dioritic intrusions. The only clastic rocks associated with the limestone in this area are a few thin beds of calcareous sandstone found in the quarries at its west end.

The Pre-Cambrian clastic rocks are best exhibited at Marble mountain,¹ several miles above Phillipsburg, in New Jersey, and on the opposite side of the Delaware river, along the south side of Chesnut hill, north of Easton, in Pennsylvania. At Marble mountain, the series of which the Franklin limestone is a part is represented by as complete a succession of beds as is found anywhere in the Highlands. These have been referred to above. The area is such an instructive one, however, that it is here described again in some detail. Besides the white limestone, there occur also quartzites, quartz-breccias or conglomerates, talcose slaty rocks and deposits of lean hematite. These rocks are intruded by great dykes of pegmatite and by masses of black, dioritic rocks. Exposures are not abundant, but, from those that have been seen, it seems safe to infer that the sedimentary rocks cover an area of about one square mile at the west end of the mountain. They occupy the little knob overlooking the Delaware river and the lower slopes of the ridge for a distance of a mile from this river. Within the area are several quarries which are worked for serpentine and talc, and several open pits that were sunk in the search for hematite. A fault bounds the area on the north and separates the Franklin limestone from gneisses. Considerable movement took place along this fault, contorting the limestone and producing several metamorphic minerals, of which serpentine and talc are the most abundant. The rock is mined, crushed, and sold as mineral pulp. The limestone of this area is similar in all respects to the Franklin limestone in other areas. The quartzose and slaty rocks are closely associated with the limestone but contacts between them are covered.

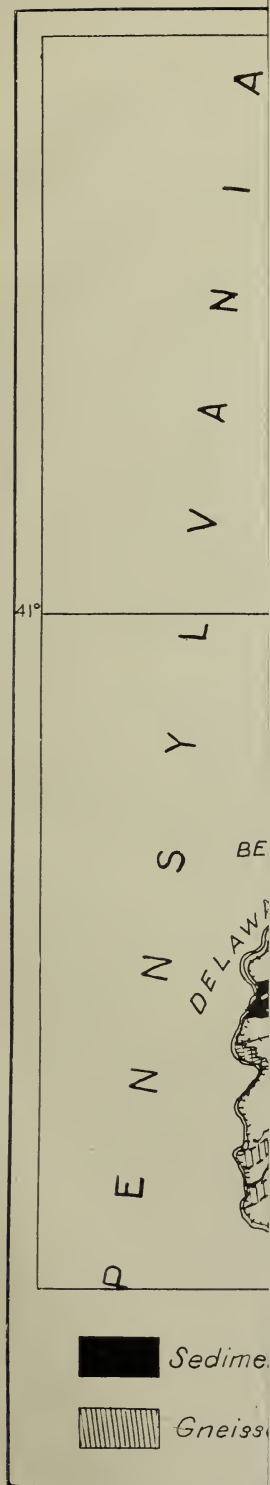
¹ PECK, F. B., *The talc deposits of Phillipsburg, N.J., and Easton, Pa.*; N.J.Geol. Survey, Ann. Rept. for 1904, pp. 161-185.

The slaty rocks comprise very schistose, light yellow or gray schists, containing a little talc, and almost massive, dense, black jasperoid beds that look very much like ancient rhyolites. With these are interbedded a few layers of quartzite conglomerates and enclosed in them are lenses of quartzite. A few of the beds are strongly ferruginous. The iron is mainly in the form of hematite, which in some cases is nearly uniformly distributed through the rocks, and in others is segregated into discs and nodules. Garnet and tourmaline are often present in both slates and quartzites. Tourmaline is especially noteworthy as it sometimes occurs as black crystals an inch or more long and one-third of an inch thick. It is particularly abundant in very schistose phases of the slates.

Thin sections of the slaty rocks show grains of hematite and magnetite in an exceedingly fine textured aggregate of chlorite and some micaceous mineral. In some sections there is a suggestion of diabasic structure in the arrangement of the dark grains in the light coloured micaceous aggregate. In others flow structure is suggested by the occurrence of the dark grains in curving and wavy streaks through the lighter matrix. On the other hand, a few sections show the dark grains in a series of parallel lines as though marking bedding, and in others lenses of the light aggregate are surrounded by hematite and magnetite as though representing pebbles in a matrix which has been replaced by iron oxides.

The general aspect of the slaty rocks is that of a series of interbedded sediments and volcanic flows that have been squeezed and metamorphosed, but no decisive evidence can be cited to determine their origin. The rocks are strongly suggestive of the Pre-Cambrian volcanic series of South mountain in Cumberland county, Pennsylvania.

The quartzites and conglomerates, which are thought to be beneath the slates, differ only in the presence of lenses of white quartz in the latter. Both are vitreous, dark gray rocks with a splintery fracture and a structure that shows no trace of foliation or schistosity. They vary from very fine grained phases to those in which the particles measure several millimetres in diameter. Occasionally they contain small subangular fragments of dense greenish-black rocks resembling the dark massive slates, but otherwise they possess no noteworthy features. The lenses of white quartz in the conglomerates vary in size from particles as small as a pin's head to others two inches in diameter. Some are round, others lenticular and others angular. The larger fragments are fractured as though crushed, and little tails of quartz mosaic extend from the ends of the lenses. The matrix in which these lie, and the entire mass of the non-conglomeratic quartzites, consist almost exclusively of quartz and hematite. The quartz is in small particles that may be sand particles, in little crescentic fragments, and in little lenticular masses of quartz mosaic, all of which lie in a finer grained ground mass composed of quartz grains, hematite and magnetite. In some cases there are also present a little secondary quartz and a few needles and large crystals of black tourmaline. All the rocks contain hematite, and it is to this constituent that their dark colour is due. The hematite is so abund-



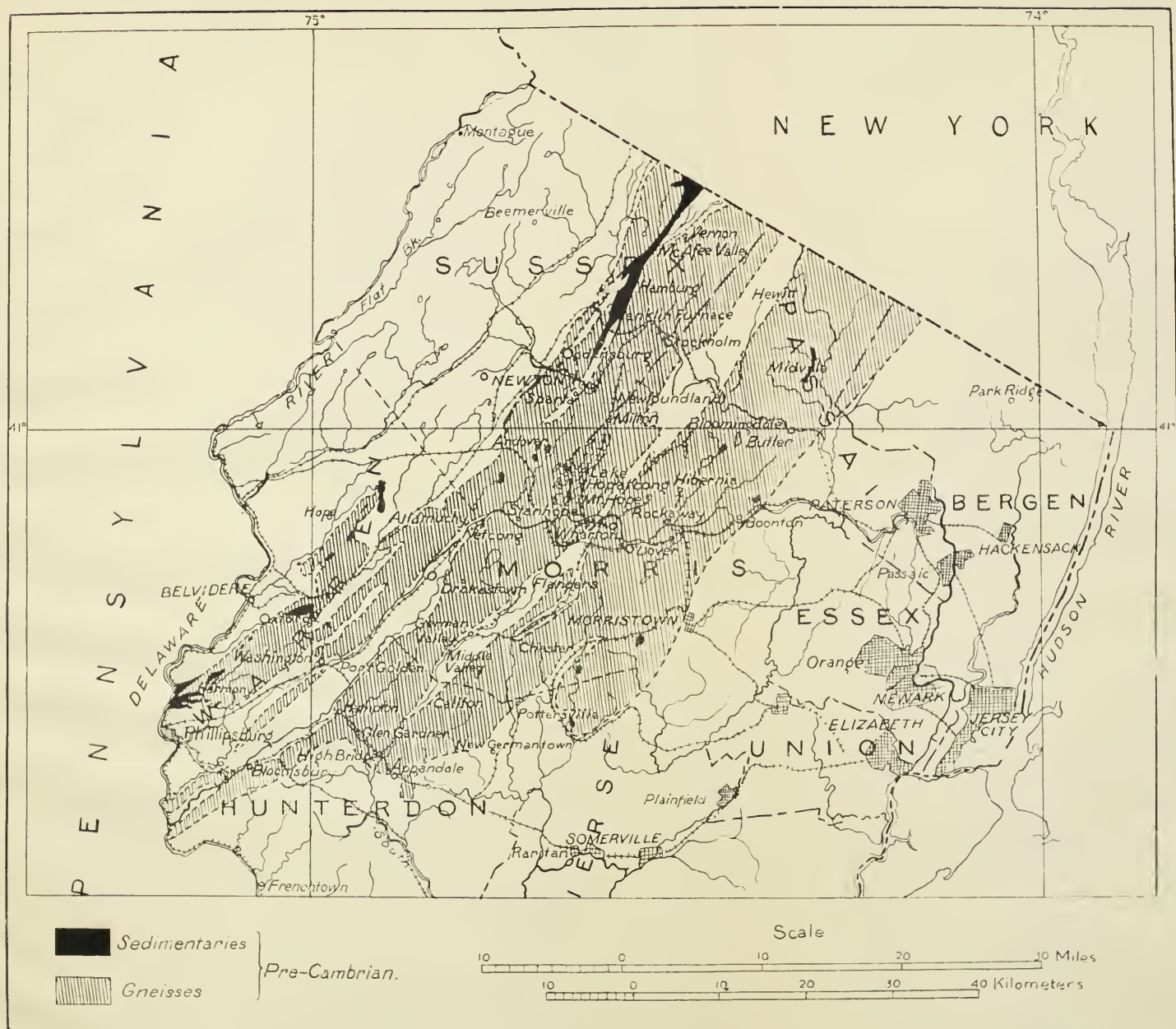


FIG. 2.—DISTRIBUTION OF PRE-CAMBRIAN SEDIMENTARY ROCKS IN THE HIGHLANDS OF NEW JERSEY.

ant in some beds, and especially in the bottom portions of beds that are locally thickened into lenses by folding, that attempts have been made to mine the rock as iron ore. Some thin beds consist of almost pure hematite, and this is often sheared to schistose masses resembling the specular ore of the Marquette district, in Michigan.

In addition to the distinctly sedimentary rocks that have been described, there are present also at Marble mountain a number of rocks of doubtful origin. One group of these questionable rocks is described by PECK¹ as "light coloured, sandy, or highly feldspathic gneisses that contain so much carbonate as to effervesce briskly with hydrochloric acid." They are declared to be interstratified with the limestones, slates and quartzites. So far as seen by the writer, the contacts between these siliceous rocks and the limestone are either fault contacts or intrusive ones. The sandy gneisses are apparently the ordinary gneisses into which some calcite has been introduced from the limestone which they intrude.

The second group of questionable rocks includes black augitic gneisses containing calcite or dolomite in thin laminæ. They weather readily into epidotic phases and, when sheared, pass over into rocks containing much biotite and resembling biotite-schists. Some of these dark gneisses may be phases of the limestone that have been so completely metamorphosed by intrusions of pegmatite and the material that produced the ordinary gneisses of the region that nearly all their original material has disappeared, and in its place have appeared diopside, hornblende, oligoclase and a little calcite, forming an aggregate of equal sized grains which is practically identical with that composing the more massive types of the black Pochuck gneisses, that are so common in the Highlands.

The main mass of Chestnut hill, on the west side of the Delaware river, opposite Marble mountain, is gneiss, but on its south slope is a belt of white limestone several hundred yards wide and extending the full length of the hill for a distance of about four miles. At its east end, near the river, the belt splits into two limbs that are separated by a mass of pegmatite. The limestone is of the same character as that on Marble mountain, but there is no quartzite associated with it. It is strongly serpentized and in places contains a great deal of talc. On its north side the limestone is everywhere in contact with gneiss, and at its west end it is bordered by the Kittatinny limestone. This boundary is evidently along a fault.

A small exposure of the same limestone has been opened up by a quarry on the north side of Bushkill creek about half a mile north of the west end of Chestnut hill. This is surrounded by the Kittatinny (Cambro-Ordovician) limestone, from which it is separated by faults.

Other exposures of the series near the Delaware river are at Lower Harmony and Roxburg. At Lower Harmony the series is represented by limestone cut by a few dykes of pegmatite. Certain beds have developed in them some light green hornblende, some biotite and a little tourmaline.

¹ Loc. cit., p. 181-2.

Others contain a few lenses of coarse feldspar mixed with light and dark green hornblende and some tourmaline. At Roxburg the white limestone is exposed in two small openings on the slope of Scott's mountain east of the village of Roxburg, where it exhibits its usual characters.

On Jenny Jump mountain, in the Raritan quadrangle, the limestone appears as a discontinuous belt lying to the east of the main crest of the mountain, as a narrower strip at the bottom of its east slope, and in a broad area at its northeast end. Much of the limestone contains the usual contact minerals, chondrodite and pyroxene, and at one place the rock is changed to a coarse grained, pink and white aggregate of calcite, dolomite, and phlogopite, that looks like a coarse grained, pink granite. At the end of the mountain there are associated with the limestone layers of fine grained, thinly bedded, micaceous, gneissic rocks. Some of these consist of quartz, feldspar, sillimanite, biotite and tourmaline. Others are composed of quartz, feldspar and pyroxene, or of the first two minerals and hornblende. The most common, however, are biotite-quartz-schists, with or without graphite, like those occurring at Tuxedo Park. In some places these rocks are crushed and much muscovite is developed in them.

The largest area of the Franklin limestone is that in which the Franklin Furnace zinc mines are situated. This begins a little south of Ogdensburg, and extends northeast with an average breadth of about three-fourths of a mile through Franklin Furnace, Rudeville and McAfee, a distance of fifteen miles, to the north boundary of New Jersey, crossing the line into New York near Amity. Although this area is occupied almost exclusively by limestone, thin beds of quartzose rock are known to occur in it at a few places, as for instance at the Simpson and Cedar Hill hematite mines already referred to.

The only other area in which fragmental rocks are known to be associated with the limestone is the narrow belt in which the Andover and Tar Hill mines are situated, which has already been described. Finally, in several little pits west and southwest of High Bridge there are exposures of a mica-graphite-schist that is similar to the graphitic schists at Tuxedo Park. There is no white limestone in the vicinity, but the High Bridge schists are so like those at Tuxedo Park that it is reasonable to regard the two as belonging in the same series.

All the other areas in New Jersey in which the Pre-Cambrian sediments are known to occur are small, and none of them show any rock but the limestone, which in many places, however, is so completely metamorphosed that little of its original character remains. The most important of these, in addition to several detached areas in the Franklin Furnace quadrangle, are: two belts south and southwest of Stag pond, a small area west of Wright's pond, two small quarries east of Cranberry lake, the Roseville mine, the Split Rock Pond mine, a quarry south of Brookside, a quarry at Turkey mountain, two miles north of Montville, and a narrow belt at Stonetown. The last named area is two and a half miles long and only about 150 feet

wide. In some places the limestone is so completely silicified that it resembles chert.

There have been no facts observed in the New Jersey Highlands that will serve as a means of separating the Pre-Cambrian sediments into a younger and an older series. The close similarity that exists between the Pre-Cambrian geology of New Jersey and that of the Adirondacks and eastern Ontario, however, suggests a correlation between the three areas. Rocks identical with those in New Jersey have been found in the two northern regions. Here they had been generally known as the Grenville series until MILLER and KNIGHT,¹ in 1907, subdivided them into a younger (Hastings) and an older series, separated by an unconformity. The younger series is correlated with the Huronian (Algonkian) of the Lake Superior region and the older series with the sedimentary portion of the Keewatin (Archæan) series in the same region. For the latter the name Grenville is retained. This series, which consists largely of limestone, was deposited on a basement of spheroidal and ellipsoidal greenstones. In New Jersey no trace has yet been found of the basement on which the Pre-Cambrian sediments were laid down; consequently, it is not possible to decide whether they should be regarded as Grenville or Hastings. In their lithological features they resemble more closely the Grenville than the Hastings rocks. Even though they be correlated with the former, doubt still remains as to whether they are Algonkian or Archæan, since the position of the Grenville beds has not been definitely established. The existence of the quartzites and conglomerates at Marble Mountain indicates clearly that, at the time the sedimentary series was laid down, a land area was furnishing sand and pebbles. Although no traces of this land have yet been found in the Highlands, its former presence is assured through the evidence of the rocks laid down off its shore.

The relations of the Pre-Cambrian sediments to the gneisses, in the midst of which they generally lie, are not clear. In many instances the contacts are along faults. In other cases they are apparently igneous. The smaller areas occupied by the Franklin limestone are elongated in the direction of the schistosity and banding of the gneisses, and mine pits seem to show that in some instances the limestone extends downward as narrow plates or lenses interlaminated with the gneiss. In still other cases, limestone and slate are surrounded, above and on both sides, by gneiss. Moreover, the limestone is frequently intruded by pegmatite that is believed to be connected genetically with the gneisses, which are thought to be of igneous origin. The linear structure, which is characteristic of the gneisses in the region, is regarded as the direct result of flowage of a viscous magma and of its crystallization under the influence of the strains produced by the flowage.²

¹ MILLER, W. G., and KNIGHT, C. W., *The Grenville-Hastings unconformity and the probable identity in age of the Grenville limestone with the Keewatin iron formation of the Lake Superior region*; Sixteenth Ann. Rept. Bur. Mines, Ontario, 1907, pp. 221-223.

² Compare BAYLEY, W. S., Passaic folio (No. 157), Geol. Atlas U. S., U. S. G. S., 1908, p. 2, and SPENCER, A. C., Franklin Furnace folio (No. 161), Geol. Atlas U. S., U. S. G. S., 1908, p. 2.

The magmas are thought to have intruded a series of pre-existing sediments and to have assumed their present structures as the result of the control exercised by the arrangement of the sedimentary beds. The larger areas of the sedimentary series may represent remnants of a more widely spread series of beds that were broken up and partly absorbed in the material of the gneisses; and the small areas surrounded by pegmatite or gneiss may be simply fragments that were floated from their original positions but not completely dissolved.

From the brief descriptions that have been given, it will be realized that the Franklin limestone is only one member of a Pre-Cambrian series of rocks including, in addition to the limestone, also quartzites, conglomerates, slates and micaceous schists. Many of these rocks have been so thoroughly metamorphosed that their fragmental character is greatly obscured. There can be no doubt, however, that they are sediments older than the gneisses which surround them, and that they represent a continuous deposition in Pre-Cambrian seas. Farther southwest, in Pennsylvania, as has been related, Miss BASCOM proposes to separate the clastic sediments from the limestone and to call them the Pickering gneiss. MILLER, however, thinks that there is a gradation between the two formations and that they represent a single period of sedimentation. In New Jersey the clastics and the limestone cannot be separated for purposes of mapping. It is probable that the white limestone in Pennsylvania can safely be regarded as the equivalent of the Franklin limestone; but that the Pickering gneiss is equivalent to the quartzites, conglomerates, slates and micaceous schists of New Jersey is not so evident. The great variety noted in the igneous gneisses of the area may be due in part to the assimilation by their magmas of the sedimentary rocks that have disappeared.

